FINAL REPORT

VERTICAL DISTRIBTUTION OF ULTRAPHYTOPLANKTON IN THE EASTERN MEDITERRANEAN UNDER STRATIFIED CONDITIONS

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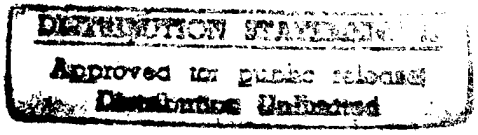

Vertical Distribution of Ultraphytoplankton in the Eastern Mediterranean under Stratified Conditions

OVERVIEW

The Levantine basin of the Eastern Mediterranean is among the most optically clear marine environments. It is highly oligotrophic, with N:P ratios often exceeding 25, strongly suggestive that primary production is phosphorus limited (Krom et al, *Limnol. Oceanogr.* **36**:424-432). The general circulation is dominated by semi-permanent and permanent mesoscale eddies linked by energetic jets and currents (Plate 1). Based on a preliminary study conducted in the Shikmona eddy in 1989 (cf. Berman et al., 1990, *EOS*, **71**:176), I hypothesized that the Eastern Mediterranean offered a natural laboratory in which the principal niche parameters defining the vertical distribution of *Synechoccocus*, prochlorophytes, and small eukaryotic ultraphytoplankton could be determined. These are the three major taxonomic groups of organisms that dominate the phytoplankton in stratified oligotrophic waters throughout most of the world ocean. In the Sargasso Sea and Indian Ocean, they show pronounced vertical zonation near the base of the euphotic zone, with *Synechococcus* dominating the community just above the deep chlorophyll maximum (DCM), small eukaryotes and prochlorophytes occurring together as codominants in the DCM, and prochlorophytes dominating the phytoplankton in zones between the base of the DCM and the 0.1% light level (Li and Wood, 1988, *Deep-Sea Res.*, **35**:1615; Li et al.,1992, *Deep-Sea Res.*, **39**:501; Olsen et al. 1990, *Deep-Sea Res.*, **37**:1033-51). Unfortunately, it is essentially impossible to determine which niche parameters are responsible for this depth-dependent variation in community structure because nutrient availability, temperature, total irradiance, and spectral quality of the light field all tend to vary in a strongly correlated way at the base of the euphotic zone in most stratified oligotrophic environments. Because of this covariance, and the fact that gradients in these parameters are often condensed into a narrow (~50m) depth interval, it is very difficult to study the importance of any one parameter individually. However, because the Eastern Mediterranean is so transparent, the preliminary data suggested that the transition from 1.0% to 0.1% light would occur below the depth at which there was a transition from a blue-green to a monochromatically blue light field; additionally, it appeared that the eddy structure effectively uncoupled variation in the depth of the nutricline from variation in the depth of the base of the euphotic zone and/or the depth of the surface mixed layer. Under these conditions, a field experiment to examine the role of abiotic factors in determining the vertical distribution of different ultraphytoplankton taxa was feasible.

The primary objectives of this project were, therefore:

1) to obtain highly resolved vertical profiles of the aubundance of major ultraphyto-plankton groups in the Eastern Mediterranean as part of a synoptic data set that would permit sub-basin scale mapping of cell number, nutrient concentration, irradiance fields, and quasi-geostrophic flow fields,

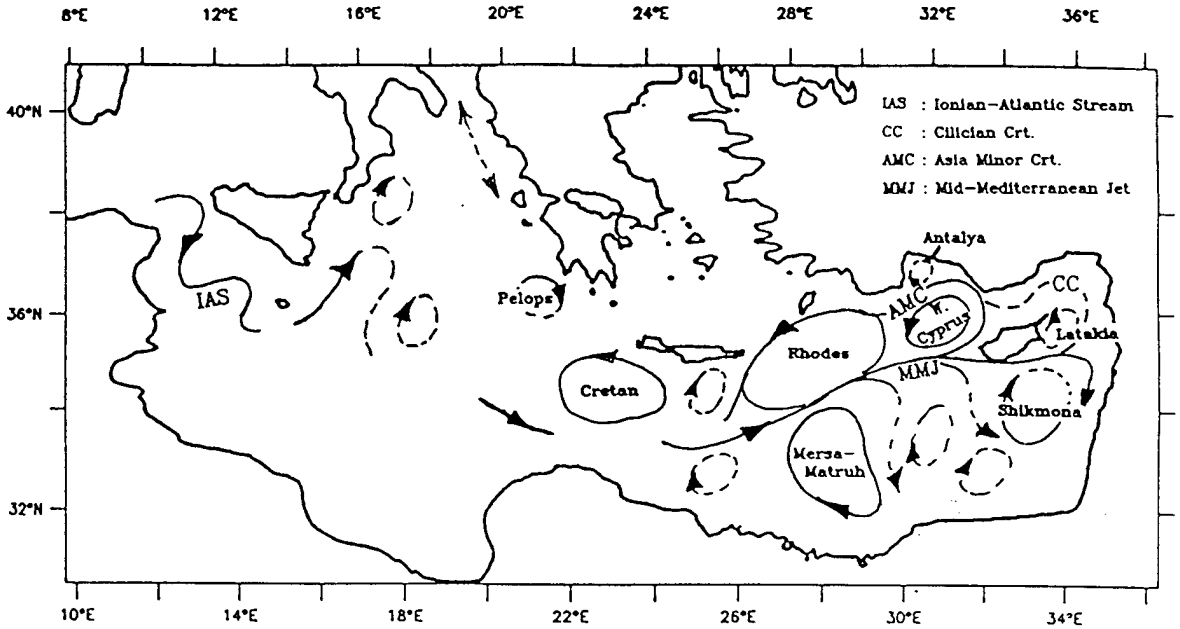

Fig. 7. General circulation schematic (from Robinson et al., 1991, fig. 2).

TABLE 1

Upper thermocline features (from Robinson et al., 1991, table 1)

Features	Type	ON 85	MA 86	MA 87	AS 87
Ionian Atlantic Stream	P	–	–	Y	Y
Mid Med. Current	P	Y	Y	–	Y
Asia Minor Current	P	Y	N	Y	N
Cilician Current	R	Y	Y	–	Y
Southeast Levantine Jets	T	Y	Y	–	Y
Rhodes C	P	Y	Y	–	Y
West Cyprus C	P	Y	Y	–	Y
Mersa Matruh AC	P	Y	Y	–	Y
Cretan Sea C	P	Y	?	–	Y
Shikmona AC	R	Y	Y	–	Y
Latakia C	R	Y	N	N	Y
Antalya AC	R	?	Y	–	N
Pelops AC	?	–	Y	?	Y
Ionian eddies AC	T	–	–	–	Y
SE Levantine eddies AC	T	Y	Y	–	Y
Eddies in the Strait of Crete	T	Y	Y	–	Y

Definitions: P = Permanent, R = Recurrent, T = Transient, ? = Not enough information to classify, C = Cyclone, AC = Anticyclone.

Plate 1. General circulation of the Levantine Basin and characteristics of upper thermocline features. [Figure 7 and Table 1 from Robinson et al., 1992, *Earth-Sci Revs.*, 32:285-309]

2) to determine the relative importance of nutrient concentration, total irradiance, and the spectral compostion of the light field in determining the lower limit of *Synechococcus* distribution in stratified oligotrophic water.
3) to make a preliminary assessment of the hypothesis that mixed layer and pycnocline populations of major ultraphytoplankton groups are genetically distinct.

Sampling for this project was conducted in collaboration with scientists from the Marine Sciences Institute of the Middle East Technical University (METU, Erdemli-Icel, Turkey) and the Israel Oceanographic and Limnological Research Institution (IOLR, Haifa.Eilat, and Tiberias, Israel) as part of the international program, POEM/BC (Physical Oceanography of the Eastern Mediterranean/Biological and Chemical Experiment) chaired by A. Robinson and J. McCarthy (Harvard University) and P. Malanotte-Rizolli (M.I.T.).

FIELD PROGRAM

The entire Eastern Levantine Basin was mapped under highly stratified conditions in fall, 1992; CTD stations were evenly spaced in a hydrographic grid between 26E and 35E; nutrient data and biological data were collected at a selected subset of these stations (cf. Fig. 1 of Yacobi et al., attached). The southern portion of the basin was sampled by the IOLR vessel, R/V Shikmona, and ultraphytoplankton samples were collected for me on that cruise by Tamar Zohary, (Staff Scientist, Kinneret Limnological Laboratory, Tiberias, Israel). The northern half of the basin was sampled by the METU vessel, R/V Bilim, and ultraphytoplankton samples were collected by myself and METU students that I trained during the cruise. The sampling approach for phytoplankton involved high density sampling for counting of phytoplankton by epifluorescence microscopy and low density sampling for flow cytometry and HPLC pigment analysis. The latter types of data were necessary to verify the presence of prochlorophytes because they are often too dim to be counted by epifluorescence microscopy, and to provide data needed to describe the underwater light field. These were run for me by R.Goericke (HPLC) and W.K.W. Li (flow cytometry). Physical data, irradiance data, and nutrient data were collected as part of the core POEM/BC measurements.

MAJOR RESULTS

1. In addition to the major permanent and recurrent upper thermocline features shown in Plate 1, an extremely strong anticyclone was observed southeast of Crete; this feature was not emphasized in earlier reviews of the general circulation of the Eastern Mediterranean (compare Plate 1 from Robinson et al., 1992, with Fig. 2 in Yacobi et al., 1995, attached).

2. Deep mixing in the anticyclonic eddy southeast of Crete disrupted the deep chlorophyll maximum at stations located nearby; however, throughout the rest of the basin, the DCM appeared as a continuous layer, extending like a sheet of chlorophyll-rich particles between 90 and 110 meters in the southeastern Mediterranean and shoaling near the Rhodes Gyre.

3. Cells in the DCM were predominantly prochlorophytes and small eukaryotic ultraphytoplankton. *Synechococcus* showed abundance maxima in the mixed layer, and in the pycnocline above the DCM, but showed dramatic decreases in abundance below 90m, except at stations associated with deep mixing in the anticyclone southeast of Crete.

4. Large diatoms in the genus *Peudo-nitzschia* reached bloom proportions near the Rhodes Gyre and appeared to advected from the surface along down-ward sloping isopycnals at the edges of the eddy.

5. The acclimated growth rate of *Synechococcus* isolated from the mixed layer and thermocline of a single station northeast of Cyprus show significant genetic variability among clones, and also indicate that the growth rate of surface populations is probably much faster than pycnocline populations. This does *not* result from genetic differences between clones isolated from the two different environments but, rather, reflects the fact that, under saturating light intensities, all clones grew faster at mixed layer temperatures than at thermocline temperatures (cf. Wood et al., 1996, attached).

PUBLICATIONS

Li, W.K.W., T. Zohary, Y.Z. Yacobi, and A.M. Wood. 1993. Ultraphytoplankton in the eastern Mediterranean Sea: towards deriving phytoplantkon biomass from flow cytometric measurements of abundance, fluorescence, and scatter. *Marine Ecology Progress Series*, Vol. **102**:79-87.

Yacobi, Y. Z., T. Zohary, N. Kress, A. Hecht, R.D. Robarts, M. Waiser, A.M. Wood, and W.K.W. Li. 1995. Chlorophyll distribution throughout the southeastern Mediterranean in relation to the physical structure of the water mass. *J. Mar. Systems*, **6**:179-190.

Wood, A. M, F. Garcia-Pichel, C. Thiemann, and M. Teiser. 1996. Acclimated growth rates of Mediterranean *Synechococcus* at thermocline and mixed layer temperatures. Report of POEM/BC workshop, Molitg-les-Bains, France, July, 1996. In Press. (attached), also published in 1995 as an abstract in *Journal of Phycology*, 31(Suppl.):23.

Wood, A.M. *with* E. Ozsoy, A. Yilmaz, N. Kress, T. Zohary, A. Hecht, I. Salihoglu, Z. Uysal, W.K.W. Li, and R. Goericke. Environmental parameters governing the distribution of ultraphytoplankton in the Levantine Basin of the Eastern Mediterranean: a model for understanding the niche dimensions of marine *Synechococcus*. In Preparation[1].

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[1] This is a key paper from this project and it has taken a long time to integrate the nutrient data from the northern and southern surveys. At the recent POEM/BC meeting in France, I met with most of the coasuthors and they continue to be interested in completing the paper. Dr. Ozsoy (METU) has the data to do the basin-wide analysis for this paper and that Drs. Yilmaz, Salihoglu, and Kress are in the final stages of intercalibrating the chemical data sets. Dr. Kress will be on sabbatical in the U.S. during 1996-97, and will have the data from these cruises with her; we have planned a meeting to follow up on the preparation of the paper once the intercalibrated data set is complete.

PRESENTATIONS

Wood, A.M., F. Garcia-Pichel, S. Miller, C. Wingard. Genetic variation in the acclimated growth rates of eukaryotic ultraphytoplankton from the Eastern Mediterranean Sea. Presented at Symposium in honor of L.R. Pomeroy, University of Georgia, Athens, GA., Oct., 1994.

Wood, A. M., F. Garcia-Pichel, C. Thiemann, and M. Teiser. The Eastern Mediterranean as a model system for the study of ultraphytoplankton in stratified oligotrophic systems. Presented at POEM/MAST/POEM-BC Symposium and workshop, Molitg-les-Bains, France, July, 1996.

EDUCATION

This grant did not provide salary support for students or postdocs. However, the following students and postdocs received training in phytoplankton culture, isolation, and enumeration as a result of this project:

1) Undergraduates:
   Janna Furusho (Pacific Island Native)
   Chris Wingard
   Cindy Thiemann (Ms.Thiemann received fellowship support from the Howard Hughes Foundation and an NSF Training Grant for a summer research on this project).
2) Graduate Students:
   Scott Miller (Ph.D. rotation project at Univ. of Oregon, 1993)
   Tracie Nadeau (Ph.D. rotation project at Univ. of Oregon, 1994)
   Dilek Eideger (Ph.D. student at METU; degree awarded 1995)
   Zahit Uysal (Ph.D. student at METU; degree awarded 1995)

3) Postdoctoral Students:
   Ferran Garcia-Pichel
   Markolf Teiser

CONNECTION TO OTHER PROGRAMS AND PROGNOSIS FOR FUTURE WORK

1. Dr. Zahit Uysal, who participated in this project when he was a student at METU, was awarded a NATO Postdoctoral fellowship to study in my laboratory in 1995. He is now an Assistant Professor at the Marine Institute of METU and we anticipate continued collaboration on processes in the Black Sea and Mediterranean.

2. I was invited to attend the POEM/MAST symposium at Molitg-les-Bains, France, in July, 1996, and to participate in the subsequent POEM/BC workshop. The purpose of the workshop was to plan a field season in 1988-89 that would collect data needed to parameterize a whole ecosystem model for the Eastern Mediterranean. I co-chaired the session on instrumentation and methods with Ilkay Salihoglu

(METU), and presented hypotheses about ways that the general circulation contributed to the maintenance of low N:P ratios and low productivity in the basin in the "Synthesis" session.

3. Understanding of the dynamics of Eastern Mediterranean has reached the point that development of a fully integrated, physically-forced model of primary and secondary production is an easily conceived reality . The Eastern Mediterranean is also an excellent laboratory for the study of oligotrophic and/or optically transparent environments since the well-studied system of eddies allows for an unusual degree of predictability regarding the conditions that will prevail at particular station locations. It is a primary site for research by the European Community under MAST. It is important that U.S. funding agencies continue to support the participation of American researchers in this ongoing research. Involvement of a U.S. ship in the 1998/99 POEM research would be very desirable. Support from U.S. agencies for participation in the cruises of other countries would be a cost-effective way to permit U.S. scientists to be part of a very productive program.